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A NEW METHOD FOR THE CORRECTION OF γ - γ CORRELATION MATRICES

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A new method for the correction of γ - γ correlation matrices based on the unfolding of the detector response function is presented. Results from this unfolding method are given for coincidence data from the reaction $^{24}\text{Mg} + ^{16}\text{O}$ at a beam energy of 44 MeV. The method is compared with the standard correction method introduced by Andersen.

1. Introduction

Information about the structure of rotational nuclei at high rotational frequencies can be obtained from the study of γ -ray transitions in the quasi-continuous energy region. Although, due to the high density of states in this energy region, these transitions cannot be associated with discrete peaks in the γ -ray spectra, it is of great interest to search for correlations in the decay pattern. Usually the data are obtained by means of coincidence experiments in which different types of γ -ray detectors are employed [large-volume NaI(Tl), Ge(Li) detectors or Compton-suppression spectrometers]. In order to extract the photopeak-photopeak events from a (large) background of Compton-scattered and random events, a reduction method is commonly used which has been proposed by Andersen [1,2]. This method essentially is based on the assumption that the number of correlated events of interest (the photopeak-photopeak events) in a coincidence matrix is negligible compared to the total number of events detected, and that events which do not correspond to photopeaks are more or less randomly distributed in the $E_{\gamma 1}$ vs $E_{\gamma 2}$

plane. In experiments with two (or more) Compton-suppression spectrometers (CSS), however, the number of correlated events constitutes already a significant part of the data. For the type of detector system we use [3], roughly 36% of the coincidences are photopeak events, a number to be compared with only 2% for bare Ge detectors and 16% for NaI detectors (see table 1). (Note that random events are disregarded in this discussion.) Moreover, a large part of the non-photopeak events is not randomly distributed over the γ - γ coincidence matrix, but rather is concentrated in narrow ridges running from the photopeaks to lower energies. These ridges, which consist of photopeak-Compton events, make up almost 50% of the coincidences. The remaining 16% Compton-Compton coincidences will indeed be smeared out in a reasonably random manner over the plane defined by the photopeak-Compton edges.

We conclude that the basic assumption in the Andersen method is not fulfilled for this type of detector system, especially with respect to the relatively large number of photopeak-photopeak coincidences and the pronounced Compton ridges. In this paper we will describe a correction method which is based on the physical origin of the background and compare the results with matrices corrected by the Andersen method.

2. Formalism

A method for the correction of Compton-scattered events has been developed which is based on the response function of Compton-suppression spectrometers. At first instance we have restricted ourselves to the correction of the photopeak-Compton ridges only. This limitation mainly was imposed by the fact that the program had to be implemented on a PDP-11/70 minicomputer and therefore the correction of all scattered events would have increased the already large

Table 1
The relative numbers of the three types of coincident events for different detector systems. Compared are bare Ge detectors, large volume NaI crystals and Compton-suppression spectrometers.

	Ge x Ge NaI x NaI CSS x CSS		
Peak to total ratio of a single detector (%)	15	40	60
Peak-peak coincidences (%)	2	16	36
Peak-Compton coincidences (%) 2×13	2×24	2×24	
Compton-Compton coincidences (%)	72	36	16

computation times beyond reasonable limits. An extension of the method, however, to the correction of Compton-Compton events should be straightforward. Secondly we decided to use as few parameters as possible in the description of the Compton ridges, again in order to minimize calculation times. From the form of the Compton ridge in singles spectra we deduced that an exponential function will fit the ridge in a reasonable way.

For the contribution to the background N_{bg} at an energy E_y , resulting from a photopeak with intensity N at energy E'_y , therefore we have taken:

$$N_{bg}(E_y, E'_y) = cN(E'_y) \exp[\alpha x(x - \beta)],$$

where $x = E_y/E'_y$. To correct for the energy-dependent detector efficiency $c = \gamma(E'_y)^{-1}$ has been used. In this formalism α , β and γ are adjustable parameters. (Note that γ is a measure for the "step function" which is usually applied when a spectrum slice with a peak is fitted with a Gaussian function superposed on a polynomial background.) The corrected number of events with energy E_y will then be:

$$N_{corr}(E_y) = N(E_y) - \sum_{E'_y > E_y} N_{bg}(E_y, E'_y),$$

where we sum over all energies higher than E_y . The parameters α , β and γ are determined from the require-

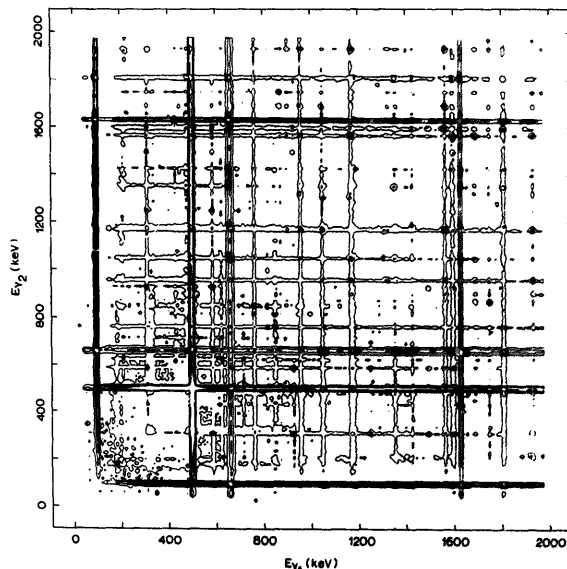


Fig. 1. Contour plots of a part of the symmetrized γ - γ coincidence matrix resulting from the $^{16}\text{O} + ^{24}\text{Mg}$ reaction. Levels shown are 200, 600, 1200, 2000, 3000 and 4000 counts, respectively.

ment that correlation matrices resulting from radioactive sources (^{22}Na , ^{60}Co and ^{152}Eu) are properly corrected (i.e. the background is minimized). Apart from the continuum γ -radiation and count-rate effects there is no reason to expect that matrices obtained in on-line experiments are different. In our formalism the matrices are corrected under the assumption that each non-zero intensity in principle is a photopeak-photopeak coincidence and has its associated Compton ridges. The correction therefore must be started at the high-energy part of the matrix. Any intensity outside of the ADC range is neglected.

It is important that the parametrisation of the detector response function has to be extracted from data

obtained from a set-up with a geometry similar to the one used in the actual experiment. The geometry of the set-up namely can introduce effects different from those encountered when only a single Compton-suppression spectrometer is used (e.g. the "back-scatter" peak).

Although in principle the correction could be extended to experiments with other types of detectors (by applying a different response function), the method is especially suited for Compton-suppression spectrometers. The worse resolution of large NaI(Tl) detectors introduces larger errors in the form of the Compton edge, whereas for bare Ge detectors the relatively small number of photopeak-photopeak events, compared to the background, makes the method highly unreliable

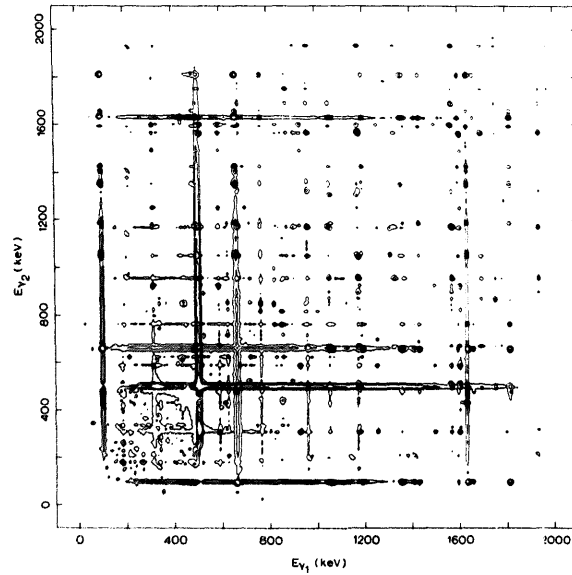


Fig. 2. Same as fig. 1, corrected using the unfolding method discussed in this article.

due to the large errors introduced by the subtraction process.

3. Results

The correction method has been tested on a γ - γ correlation matrix from a coincidence experiment on ^{39}K [4] with the $^{24}\text{Mg} + ^{16}\text{O}$ reaction at a beam energy $E(^{16}\text{O}^{5+}) = 44$ MeV. The two spectrometers used in the experiment were positioned at 90° with respect to the beam direction. Due to the fact that the spectrometers were directly facing each other in this set-up, the 511 keV annihilation line is very pronounced in the coinci-

dence matrix. For both spectrometers the suppression factor was already better than 10. Compared to reactions producing heavier nuclei at higher incident energies, this reaction has the advantage that the resulting matrix should be free from the continuum γ -rays due to unresolved transitions between high-energy states in the formed nuclei. Therefore only discrete peaks should remain in the matrix after the correction has been applied. The continuous background would make conclusions about the correctness of the method much harder to draw.

Prior to the application of both methods the matrix was partly corrected for random events using a timegate in the Δt -spectrum. To enhance visual appearance the

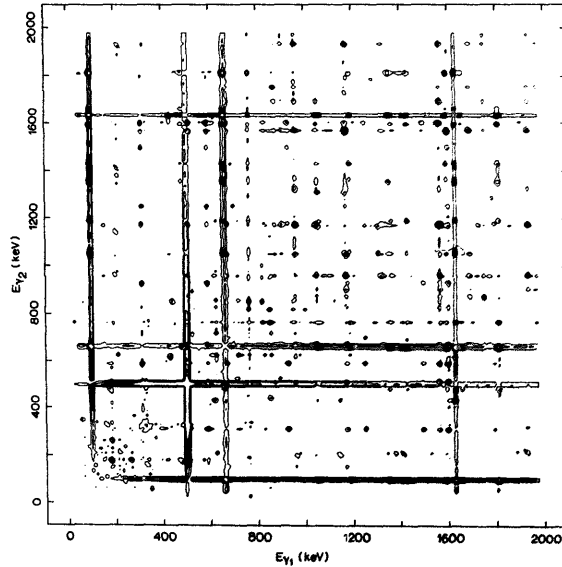


Fig. 3. Same as in fig. 1, corrected using the iterative method from Andersen [1,2]

matrix was also symmetrised. Contour plots of a part of the matrix before and after the correction are shown in figs. 1 and 2. The Andersen-corrected matrix is displayed in fig. 3. For all three matrices the dispersion is 9.23 keV per channel, resulting from a compression of 4 K ADC data to a 256×256 channel matrix. A comparison of both corrected matrices (figs. 2 and 3) shows their similarity. Although experience has learned [5] that a one-pass Andersen correction of a coincidence matrix from two Compton-suppression spectrometers results in an overcorrection of the Compton ridges (especially at

the positions where two ridges meet), the iterative procedure smoothes this effect. Obviously the method is sensitive enough to handle the discrete ridges well. The unfolding method corrects the ridges somewhat better (see also below), but performs worse at energies above the photopeak-photopeak intensities where coincidences are random.

Both methods are compared in more detail by means of the projection of a slice around 1260 keV onto the horizontal axis, as illustrated in fig. 4. For comparison a spectrum which has been corrected for random events

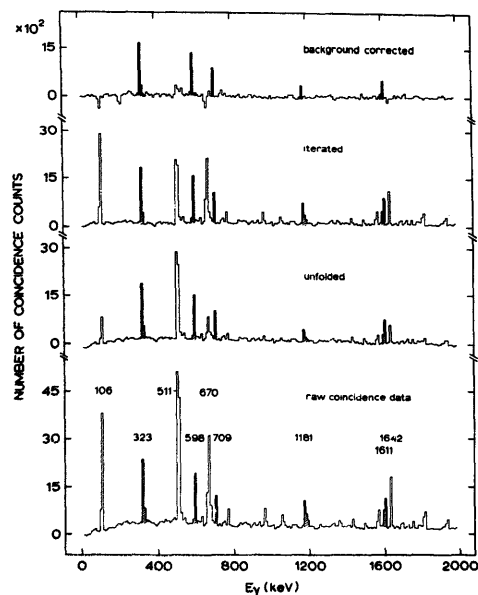


Fig. 4. Spectra resulting from a projection of a slice around 1260 keV onto the horizontal axis. Presented from the bottom upward are (a) a projection in the original matrix; (b) a projection in the unfolded matrix; (c) a projection in the iterated matrix; (d) the background corrected spectrum. Lines which are present also in the background corrected spectrum are hatched. This last spectrum is included for reference purposes only. See text.

in the "usual" way (by subtracting a "background" spectrum resulting from the projection of an adjacent slice) is also included. This last spectrum may be used as a reference as to which peaks should be suppressed in the corrected spectra when compared to the original. In the spectrum only the 323, 598, 1181 and 1611 keV lines coincident with the 1264 keV transition in ^{39}Ar [6] are still present (the hatched peaks in fig. 4). The 709 keV peak also present is coincident with the 1262 keV transition in ^{30}P [7], which is also contained in the projection gate. In both the unfolded and iterated spectra indeed the other peaks (notably the 106, 670 and 1642 keV lines from ^{39}Ar [8], and the 511 keV annihilation line) are reduced relative to the ^{39}Ar lines, as a result from the partial removal of the Compton background present in the slice. With the exception of the 511 keV line all contaminating peaks are better suppressed in the unfolded spectrum. As has been stressed before this contaminant cannot be properly corrected by the unfolding method because it does not consist of Compton-scattered events. That the ridges stretching from the annihilation peak towards higher energies are nevertheless partially suppressed is a result from the unfolding procedure which corrects for the spurious intensity in the ridges as if these consisted of photopeaks. It should be noted that this problem is noticeably present only in the case of the 511 keV peak which height is larger than all other peaks present in the matrix by a factor of at least 15.

4. Conclusions

The results from the two correction methods clearly indicate that they are at least comparable in performance. The unfolding method, however, has the advantage that it is more transparent, physically speaking, and still is susceptible for improvements. In theory the unfolding method as it is should be able to increase the

relative number of photopeak-photopeak coincidences to about 70% of the total contents of the matrix, a number which will be somewhat lower in practice due to the presence of random events and the fact that the response function which we use can only be an approximation. Because random events seem to be reasonably well corrected by the iterative method without affecting the photopeaks too much, a combination of both methods will probably produce even better results. Further improvements could include a better parametrisation of the response function and a correction for the backscatter peak. Obviously another set-up than the face-to-face geometry used in this experiment would reduce the dominant 511 keV peak considerably.

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